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Clay mineralogy of Glacial Lake Missoula varves Missoula County Montana

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CLAY MINERALOGY OF GLACIAL LAKE MISSOULA VARVES

MISSOULA COUNTY, MONTANA

by

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ABSTRACT

The varved sediments exposed in Missoula Valley were deposited in Glacial Lake Missoula during the Pleistocene. Three types of varves were found, simple, composite, and drainage. X-ray diffractometer analyses revealed that illite, montmorillonite, chlorite, and kaolinite are present in the order of decreasing abundance. Illite and chlorite are more abundant in the dark winter layers; montmorillonite and kaolinite are more abundant in the light summer layers. This seasonal segregation of the clay minerals is believed to have been caused by differential sedimentation. A horizontal increase in illite and decrease in montmorillonite with distance from the point of initial deposition are also attributed to differential sedimentation.

INTRODUCTION

The study of clay mineralogy has evolved rapidly during the recent years. Persons from diversified backgrounds have contributed much to its study, but more data are needed. Grim (1953, p. 355) in a discussion of glacial sediments states that "the composition of varved clays is not well known." The paucity of data on varved clays suggested a study of the Glacial Lake Missoula sediments.

The objectives of the study were (1) identification of the clay minerals in the dark and light layers of the varved lake sediments, (2) study of possible stratigraphic changes in the clay mineral suite, and (3) investigation of the horizontal distribution of the clay minerals within the Missoula Valley and surrounding areas.

Acknowledgements

I wish to thank Dr. John Hower for his many helpful criticisms and suggestions; Dr. Fred S. Honkala for his helpful criticisms; and fellow graduate student Mr. Larry Toler for his timely assistance. Gratitude is also expressed to the Montana State Highway Department for their cheerful cooperation.

Previous Work

"Varv" is a Swedish term meaning "a circle or a periodical iteration of layers" (Antevs, 1922, p. 4). Varved sediments are annual deposits of light colored silty sediments deposited during the summer months, and dark finer-grained material deposited during the winter months. Each varve is distinct and separate and can be differentiated from neighboring varves.

Varves were recognized as yearly deposits as early as 1832. De Geer in 1884, (Antevs, 1922, p. 4) was able to correlate localities and study the chronology of the ice retreat history of the last ice sheet in northern Sweden by measuring and plotting varve thicknesses. Antevs (1922, 1928, and 1951) made detailed studies of the recession of the last ice sheet in New England and Canada using De Geer's method.

Saurama (1922) made a similar study of the varved sediments in southern Finland, correlating the sediments on the basis of varve thicknesses and such primary characteristics as color and hygroscopicity of the clays. Rittenhouse (1934, p. 110) measured the physical characteristics of some varved clays from northern Canada, but did no work on the clay mineralogy. Grim (1953, p. 355) stated that in a study made on some varved sediments in Canada, illite was determined as the dominant mineral, with montmorillonite present in the dark layers but not in the light layers. Eden (1955, p. 668) investigated the physical characteristics of varved clays from Steep Rock Lake, Ontario, and reported more montmorillonite in the dark layers than in the light layers. Sahinen Smith and Lawson (1958, p. 29) stated that x-ray analyses of glacial sediments sampled in Missoula, Montana, showed kaolinite and montmorillonite to be present.

Geologic History of Missoula Valley

Missoula Valley is thought to be of Laramide origin. Erosion during the Mid-Tertiary formed the sub-summit surface which can be seen on the mountains that encircle Missoula Valley. Degradation during formation of the sub-summit surface contributed to the formation of Eocene and Miocene (continental) beds. Late Tertiary uplift rejuvenated the ancient Bitterroot River, superimposing it onto a number of spurs of Beltian bedrock which extend into Missoula Valley (Eakins and Honkala, 1952, p. 1361).

During the Pleistocene, a lobe of Cordillerian ice moved southward down the Purcell Trench into northern Idaho terminating in the basin of Pend-Oreille near the Idaho-Montana state line (Fig. 1). This dammed the Clark Fork River and created Glacial Lake Missoula, which covered 3,300 square miles, with its highest shoreline at a maximum elevation of 4,200 feet. The greatest depth of the lake in Missoula was 1,000 feet.

The closing drainage stages of Lake Missoula were regular as indicated by the closely spaced beach lines on Mt. Jumbo and Mt. Sentinel in Missoula Valley (Pardee, 1910, p. 381; Alden, 1953, p. 154). Three sets of terraces have been formed during post-Pleistocene entrenchment of the Clark Fork River. The average depth of the entrenchment is approximately fifty feet (Eakins and Honkala, 1952, p. 1361).

General Geology of Missoula and Vicinity

The rocks in the vicinity of Missoula Valley range in age from Precambrian to Recent, with only Mesozoic systems missing. Exposure of Paleozoic rocks is limited to the Garnet Range and in western Missoula County (Fig. 2). In the Bitterroot Valley the Beltian sediments are intruded by Cretaceous granitic rocks. Tertiary volcanics are locally widespread. Pleistocene silts, sands, and gravels, and Tertiary lake sediments are found both in the Missoula and Bitterroot Valleys (Sahinen,

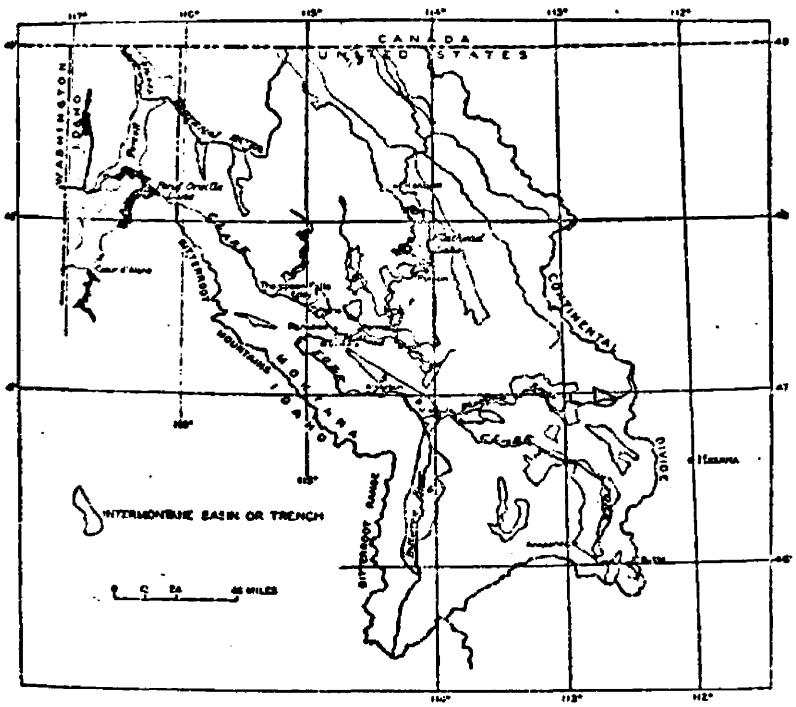


FIGURE 1.—*Index Map*

1. Mission Valley. 2. Jocko Valley. 3. Little Bitterroot Valley. 4. Missoula Valley. 5. Ninemile Valley. 6. Bitterroot Valley.

Fig. 1 The Clark Fork drainage system of which the numbered basins were submerged during the Pleistocene by Glacial Lake Missoula (From Pardee, 1942).

1957, p. 4).

Physiography

The area under investigation is located in the Rocky Mountain physiographic province. In the vicinity of Missoula it is characterized by generally north to northwest trending mountain ranges (Fig. 2). Drainage of the Missoula Valley is to the northwest by the Clark Fork River which flows to the Columbia River and ultimately to the Pacific Ocean (Fig. 1). Within the Missoula Valley and upstream, the Clark Fork is fed by a number of tributaries, principal of which are the Bitterroot and Rock Creek drainages from the south and the Blackfoot River from the north. Significant to this problem because of glaciation in its upper reaches is the relatively small Rattlesnake Creek drainage from the north in the vicinity of Missoula. West of Missoula, the Ninemile basin is drained by the small southeast flowing Ninemile Creek.

Glacial Source Areas

The varved sediments deposited in the Missoula Valley are believed to have been derived from Wisconsin age glaciers in the headwaters of the Blackfoot and Rattlesnake Valleys with a minor contribution from glaciers emptying into the Bitterroot Valley (Fig. 2). The bulk of the source material probably came from the Blackfoot Valley glacier, the farthest advance of which is marked by a moraine at Clearwater, approximately 35 miles east of Missoula (Alden, 1953, p. 108). Pardee (1942, p. 1572) believes that silts in the Missoula Valley were derived mainly from the Blackfoot Valley. The glaciated region in that area is underlain by Precambrian argillites, carbonate rocks, quartzites

Fig. 2


NATIONAL BISON RANGE
Seeley Lake
Qal
Qm

Fig. 2 Map showing sampling points in Missoula Valley and surrounding area. Taken from (Alden, 1953).

Explanation

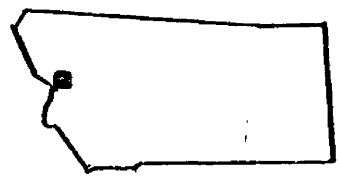
Recent

Qal
Alluvium

Qlm
Glacial Lake Missoula

Wisconsin

Qgl
Silt of Glacial Lake Missoula



Studied area

Qm
Terminal, lateral, and recessional moraines

Illinoian or Wisconsin

Qmi
Qgi
Glacial drift

Early Pleistocene

QTt
Cut terraces

Unglaciated area

Miocene

Tlb
Tertiary lake beds

Local Pleistocene glaciers

Scale 1" = 11.1 miles

Locations

and Tertiary sediments. Some of the material was also derived from the Rattlesnake glacier which is the lowest extension of the Mission Range ice center. A terminal moraine approximately five miles north of Missoula marks the farthest advance of this glacier. The glaciated area is primarily underlain by Pre-Cambrian argillites, carbonate rocks, and quartzites.

Methods of Investigation

Approximately forty days were spent in the field measuring varve thicknesses, collecting samples, and determining elevation points of areas of investigation. The varved sediments are well exposed throughout the valley, but deep mechanical weathering makes sampling and measuring impractical at many locations.

The dark and light layers were mechanically separated and dispersed in 1000 ml cylinders. Clay-sized particles (<2m) were withdrawn and centrifuged on unglazed porcelain plates. X-ray patterns were obtained with a diffractometer, utilizing copper K alpha radiation.

Size analyses of the dark and light material of the varved sediments were made with a soil hydrometer. Approximately twenty grams of dark and light material were analyzed for calcium carbonate content using hydrochloric acid. Finally a number of samples were treated with 2N potassium hydroxide solution with the purpose of identifying the source materials of the montmorillonites.

Discussion of Varve Types

Missoula Valley varves consist of simple, composite, and drainage types made up of two distinct components, a dark and light band. Varve thicknesses were controlled by seasonal variations. Exceptionally warm summers produced thick varves, while colder seasons produced thin varves. Conditions favoring formation of simple varves are low temperatures, weak thermal stratification, and great circulation in the lake waters (Antevs, 1951, p. 1254).

Composite varves, which were briefly noted by McGuire (1957, p. 201), are annual deposits whose summer components contain subordinate but distinct laminae (Antevs, 1951, p. 1261). This type of varve is abnormal and rare; it is believed to form in lakes with variable mud flows and strongly thermally stratified waters (Antevs, 1951, p. 1201). Composite and simple varves are shown in Figures 3 and 4.

Drainage varves are abnormally thick silt or sand layers produced by lake drainagos, the lakes being ponded between ice edges and higher land or by dams (Antevs, 1922, p. 69). These types are shown in Figures 5 and 6.

Descriptions of Locations

The deposits at Locations One, Two, and Eleven comprise the stratigraphic column to which vertical changes in clay mineralogy can be related.

Location One

Five miles west of Missoula on Highway 10. Sec. 7, T13 N., R. 19 W. Elevation 3180.0 ft.

The sediments are located on the north side of Highway 10 in a fifteen foot road cut where 506 varves were measured and plotted (Plate 1). The average varve thickness is 1.85 cm. Some varves exhibited folding which could be caused by grounding of icebergs, deposition in

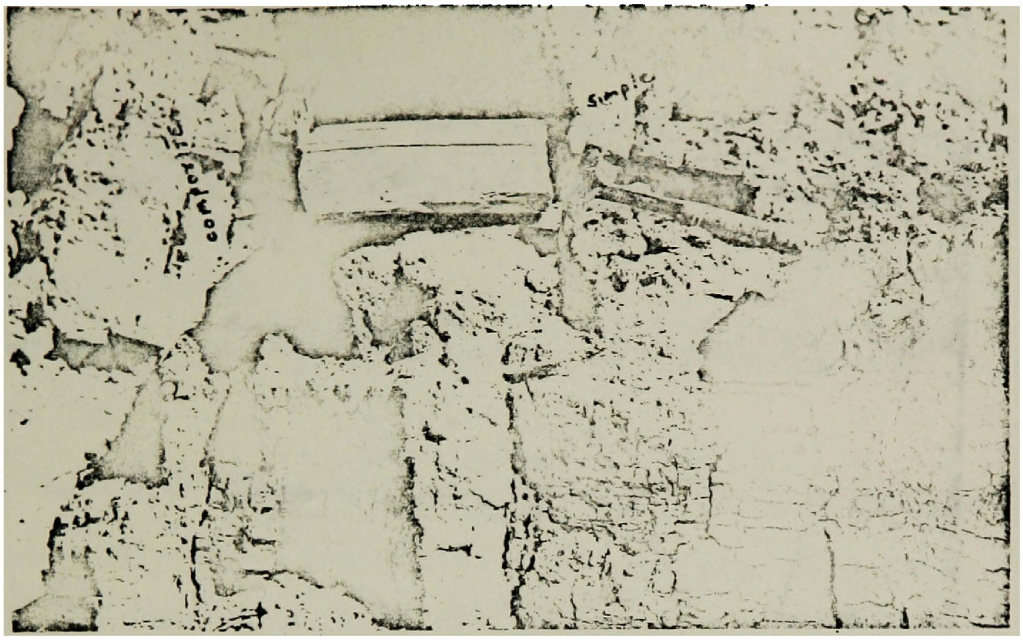


Fig. 3 Sample of varved lake silts showing simple, composite, varves and also a sand layer in lower right corner. (Taken at Location Eleven)

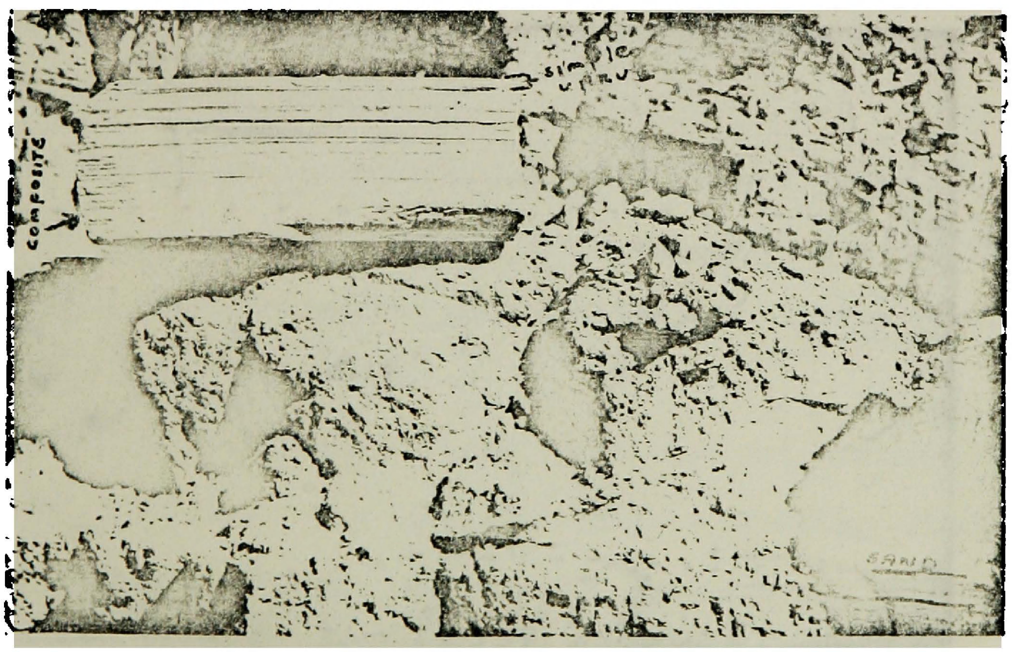


Fig. 4 Close up view of above sample.

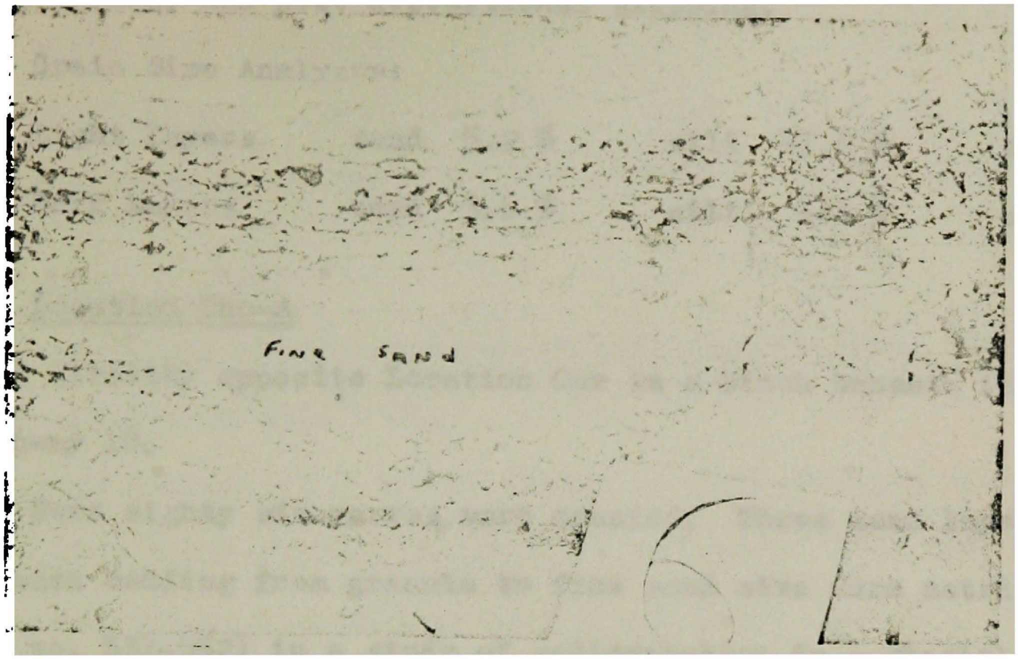


Fig. 5 Fine sand overlain by varved lake sediments. Taken approximately five miles northwest from Missoula on Mullen Road.

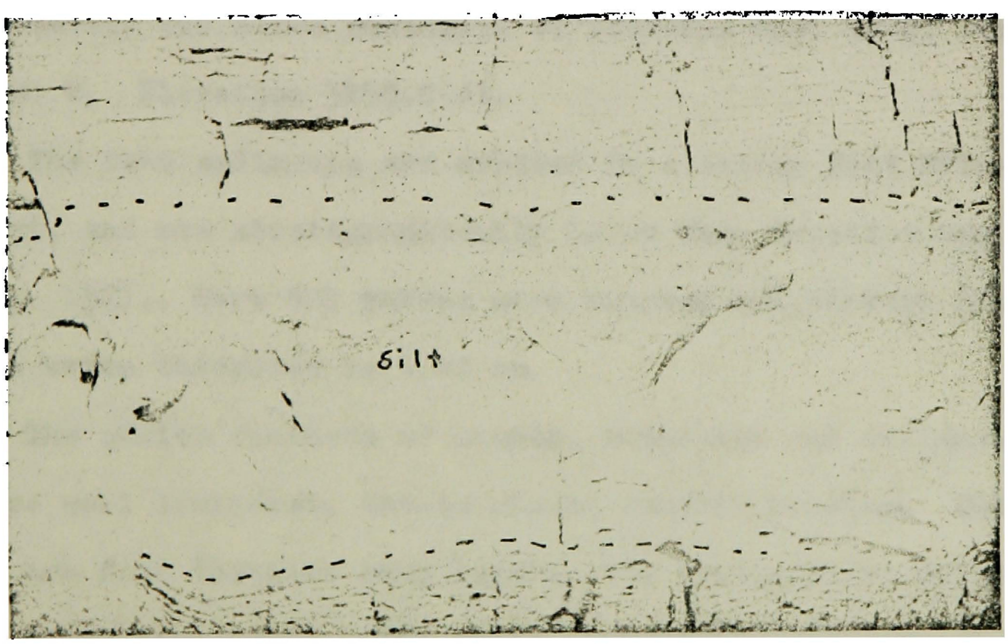


Fig. 6 Three foot thick silt layer associated with varve sediments. Taken in Location Eleven.

shallow waters, and post depositional slipping.

Grain Size Analyses:

Light Layers	sand	5.2 %	silt	47.6 %	clay	47.6 %
Dark Layers	sand	3.6 %	silt	4.6 %	clay	91.8 %

Location One-A

Located directly opposite Location One in a ditch beneath the south side of Highway 10.

Here eighty six varves were counted. Three sand layers exhibiting graded bedding from granule to fine sand size were noted. Matthews (1956, pp. 537-552) in a study of sedimentation in a glacial lake reported similar graded laminae, and attributed the grading to turbidity currents.

Location Two

Approximately two miles southwest of Location One. SE ¼, Sec. 11, T.13 N., R.20 W. Elevation 3155.0 ft.

The lake sediments are exposed in a thirty foot Milwaukee railroad cut, and are stratigraphically lower than Location One (McGuire, 1957, p. 197). Here 820 varves were counted and plotted (Plate 2). The average varve thickness is 1.42 cm.

The series consists of simple, composite and drainage varves. They are well laminated, but in places exhibit folding. The drainage varves are four distinct sand layers, the bottom layer being approximately three feet thick. The upper sand layers were traced two miles northwest along the railroad cut, and were found to grade laterally into silt and finally to pinch out. This gradation indicates that the source was from the east.

Grain Size Analyses:

Light Layers	sand	5.4 %	silt	54.2 %	clay	40.4 %
Dark Layers	sand	3.6 %	silt	7.8 %	clay	88.6 %

Location Eight

Approximately six miles northwest of Location Two. Sec. 30, T.14 N., R.20 W. Elevation 3138.0 ft.

Approximately 340 varves (Plate 4) were measured in an exposed section in a Northern Pacific railroad cut where Belt rock and gravel can be seen underlying the lacustrine sediments (Fig. 7). Alden (1953, p. 156) in discussion of this area stated that much of the lacustrine silts have been preserved from the meandering Clark Fork because of the protection afforded by underlying coarse gravel and limestone which form a bluff salient, fourteen miles northwest of Missoula (Fig. 9).

Varves are of the simple, composite, and drainage types, of which some exhibit folding (Fig. 8). Average varve thickness is 1.41 cm.

Grain Size Analyses:

Light Layers	sand	4.8 %	silt	40.1 %	clay	55.1 %
Dark Layers	sand	3.4 %	silt	32.6 %	clay	64.0 %

Location Eleven

Approximately thirteen miles west of Missoula, north side of Highway 10. Sec. 35, T.13 N., R.21 W. Elevation 3072.0 ft.

This series consists of simple, composite, and drainage varves, exhibiting more folding than the varves at Locations One and Two. Numerous lenses of sand and outwash material are distributed throughout the section suggesting possible shallow deposition with fluctuating depths. No measurements were attempted because of the complicated

Fig. 7 Mechanically weathered varve sediments overlying Belt Sediments. (Location Eight)

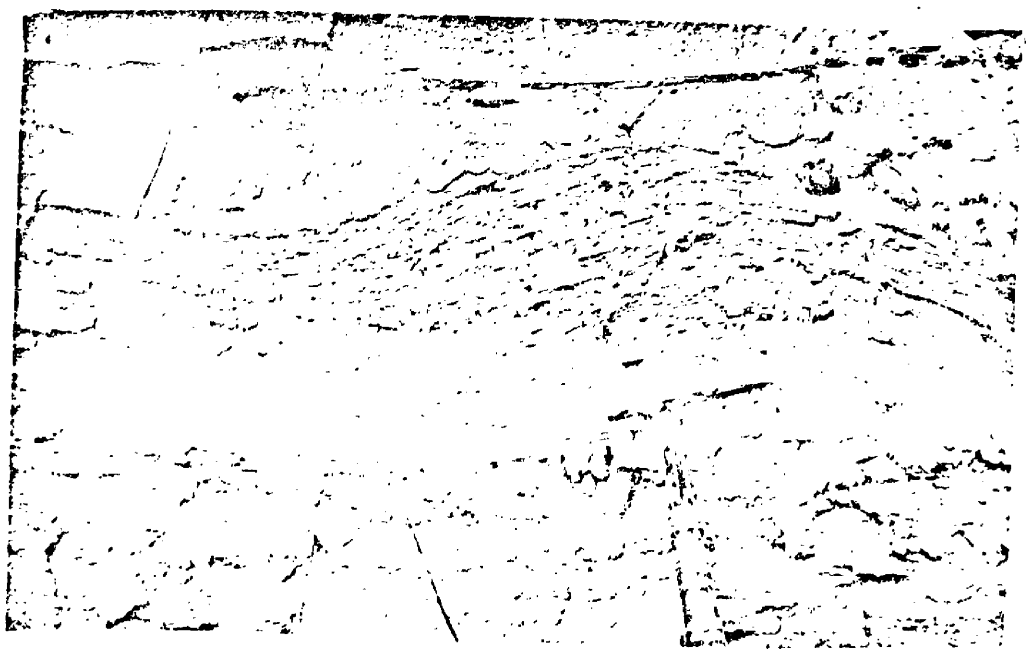


Fig. 8 Some folded varves. (Location Eight)

nature of this section.

Grain size analyses show the presence of more coarse material than at Location One and Two, suggesting that this location is relatively older. This conclusion is based on the assumption that as a glacier retreats, its distance increases away from the depositional area, thus the overlapping yearly sediments should show a decrease upward in coarse material. The postulated earlier deposition is further substantiated by the location of this section, lying farthest west of the easterly glacial source area (Fig. 2). However, contribution from nearby minor drainages is not precluded.

Grain Size Analyses:

Light Layers	sand	6.9 %	silt	34.7 %	clay	58.4 %
Dark Layers	sand	3.6 %	silt	24.4 %	clay	72.0 %

Location Twelve

One-half mile northeast of Bonner on the south side of Highway 20.

The section consists of six feet of sand and coarse material overlain by four feet of light brown clay, interlaminated with minute dark brown and yellow bands of clay. Dark layers (.62 cm.) are conspicuous in the top and bottom of the clay section.

Location Thirteen

Forty-five miles east of Missoula on Highway 20, 400 yards east of the Blackfoot River. SE $\frac{1}{4}$, Sec. 18, T.14 N., R.14 W.

Samples of dark and light material were taken from a six foot section consisting of very small winter laminations and thick summer layers. Grain size analyses were made only on the light material since mechanical separation of the dark layers was not possible without significant contamination by the light material.

Grain Size Analyses:

Light Layers	sand	11.3 %	silt	78.3 %	clay	10.4 %

Location Fifteen

Two miles east of Missoula south side of Highway 10, Sec. 13, T13 N., R.18 W.

Approximately 320 varves were measured (Plate 3). The average varve thickness is 3.63 cm. The varves at this location are twice as thick as the other measured varves in the valley. It is believed that this area was the initial site of deposition where large influxes of material would create unusually thick varves. The section is bottomed by sand and coarse material, probably a part of a sand bar. Near the top the varves appear folded and disturbed.

Grain Size Analyses:

Light Layers	sand	6.6 %	silt	59.3 %	clay	34.1 %
Dark Layers	sand	4.3 %	silt	47.9 %	clay	47.8 %

Location Twenty-One

Approximately thirty-five miles west of Missoula. Sec. 6, T.42 N., R.23 W.

A grab sample was taken from the Northern Pacific railroad cut twenty yards south of Saw Mill Gulch Road on the south side of the Clark Fork River.

Description of Section:

Layer of alluvium (top)

Five foot layer of fine sand

Three foot layer of graded sand

Layer of very fine salt

Location Thirty

Five miles east of Alberton. Sec. 3, T.14 N., R.23 W.

Samples were taken from a fifteen foot cut on the north side of Highway 10. The section consisting of simple, composite and drainage varves, overlies Belt sediments. Present near the bottom of the section are four distinct sand layers.

Grain Size Analyses:

Light Layers	sand	4.8 %	silt	54.2 %	clay	41.0 %
Dark Layers	sand	2.0 %	silt	2.6 %	clay	95.4 %

Location Forty

Two miles west of Missoula, approximately 300 yards north of Highway 10 behind Missoula Auction Company.

A fifteen foot section of coarse outwash material, exhibiting poor stratification, and containing sand and clay lenses, is exposed here (Fig. 10). Six varves were counted in one of the clay layers. The sand layers exhibit graded bedding from granule to fine sand size.

Location J-One

A grab sample was taken from a cut in Highway 93 approximately forty miles northwest of Missoula. The section which overlies consists of fine white silts and sands which exhibit varve structures (Fig. 11).

Fig. 9 View of silt terrace (Pleistocene) fourteen miles northwest of Missoula looking southeast on Mullen Road.

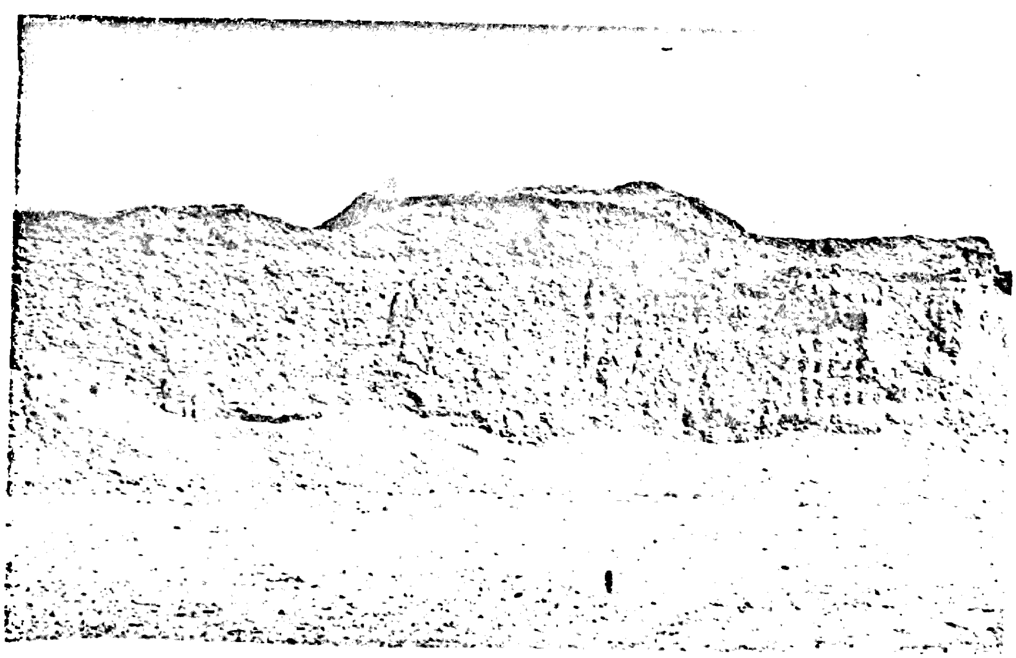


Fig. 10 Outwash material exhibiting stratification. Clay and sand lenses cannot be seen in this view. Taken two miles west of Missoula (Location Forty).

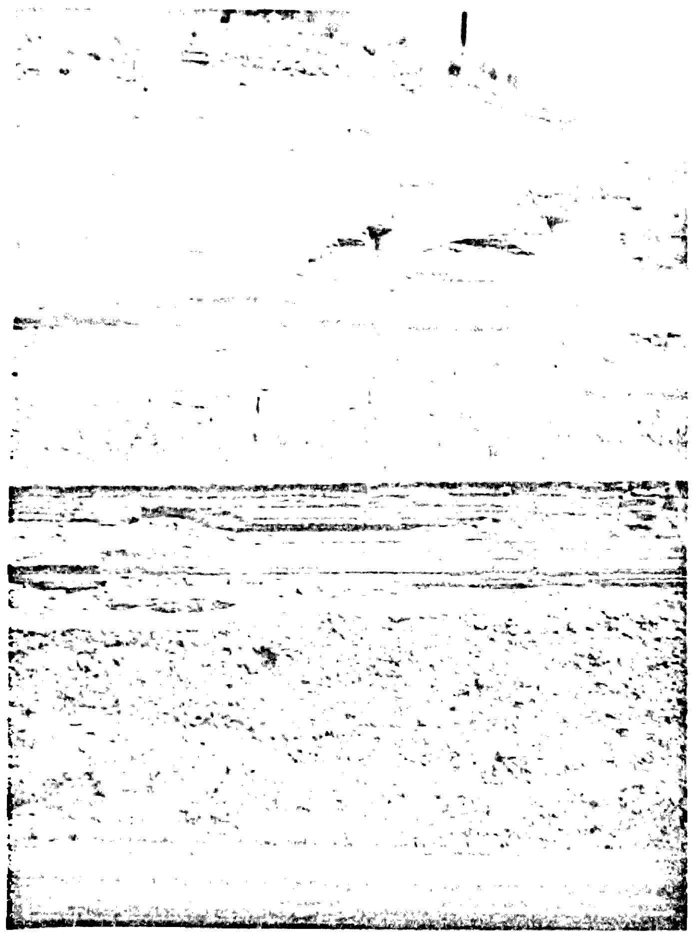


Fig. 11 Varved silts and sands overlying till in Jocko Valley (Forty miles northwest of Missoula). A six to twelve inch oxidation zone on top of till is present here.

MINERALOGY OF VARVES

Quantitative analyses of the clay-sized material reveal that illite, montmorillonite, chlorite, and kaolinite are present in order of decreasing abundance. There is more illite and chlorite in the dark winter dark layers, while montmorillonite and kaolinite are predominant in the light summer layers (Table 1).

The observed differentiation of the clay minerals may be explained in several ways:

1. Diagenetic changes in the depositional basin.
2. Differential sedimentation rates caused by a variation in density of the clay minerals.
3. Differential sedimentation caused by the flocculating properties of the clay minerals.

No evidence can be presented to prove that diagenesis was insignificant in affecting the Missoula clay minerals. But Grim (1953, p. 249) in discussing the nature of diagenesis of clays states that insignificant chemical changes occur in sediments deposited in lacustrine fresh water environments. Furthermore, the low temperatures in the Pleistocene lake waters would impede normal chemical activity found in the lakes.

The second explanation is not applicable on the basis of the following clay mineral densities from Grim (1953, p. 312).

Illite	2.76 - 3.0 gm/cm^3
Montmorillonite	2.53 - 2.74 gm/cm^3
Chlorite	2.60 - 2.96 gm/cm^3
Kaolinite	2.60 - 2.68 gm/cm^3

Table I

PERCENTAGES OF CLAY MINERALS IN DARK AND LIGHT BANDS

Location One

Sample	Montmorillonite		Illite		Chlorite		Kaolinite	
No.	D.	L.	D.	L.	D.	L.	D.	L.
A.	24.5	33.0	51.0	46.0	11.0	11.5	13.0	8.8
B.	31.0	43.0	43.0	42.0	19.5	10.0	5.8	4.2
C.	26.7	29.0	52.0	50.0	14.5	14.5	6.3	7.0
D.	31.0	30.0	52.0	47.0	21.0	12.0	1.5	11.0
E.	15.0	27.0	60.0	51.0	14.5	15.6	10.0	5.5
F.	25.0	28.0	55.0	46.0	12.0	13.5	7.3	11.2
G.	19.0	30.0	54.5	49.0	21.0	12.0	4.5	9.0
H.	25.0	24.0	51.0	47.0	20.0	13.3	3.7	10.8
Average	24.6	29.6	52.3	47.2	16.6	12.8	7.2	8.4

Location Two

Sample	Montmorillonite		Illite		Chlorite		Kaolinite	
No.	D.	L.	D.	L.	D.	L.	D.	L.
A.	17.0	21.0	60.0	56.0	15.0	12.5	9.5	9.5
B.	12.5	38.0	56.0	44.0	9.0	10.0	13.5	8.3
C.	25.0	38.0	56.0	41.0	12.7	10.2	2.0	10.4
D.	37.0	35.0	46.0	48.0	11.0	12.0	9.4	4.8
E.	27.0	28.0	52.0	50.0	16.2	17.0	7.2	4.5
F.	25.0	27.0	55.0	63.0	5.0	5.0	14.5	5.0
G.	22.0	31.0	56.0	54.0	14.5	10.5	4.0	10.7
H.	17.2	25.0	58.0	51.0	14.5	12.0	6.0	11.0
I.	20.5	31.0	53.0	48.0	23.5	17.0	5.0	2.5
J.	25.5	31.0	52.0	48.0	7.5	9.8	10.0	10.3
K.	22.0	32.0	58.0	51.0	14.5	11.5	6.5	9.5
Average	22.7	33.7	54.7	50.4	13.0	11.5	8.5	7.8

Table I
(Continued)

Location Eight

Sample No.	Montmorillonite D.	Montmorillonite L.	Illite D.	Illite L.	Chlorite D.	Chlorite L.	Kaolinite D.	Kaolinite L.
1.	27.4	37.6	46.0	44.0	15.5	8.4	11.9	10.9
2.	(silt)	(38.6)		(43.5)		(9.1)		(9.1)
3.	36.8	33.6	45.0	48.5	11.7	5.8	8.1	9.7
4.	17.5	27.0	54.5	53.0	14.8	12.7	13.1	7.4
5.	30.0	29.0	50.0	49.0	18.5	8.8	1.1	13.0
6.	22.4	37.8	56.0	46.0	16.8	9.2	5.1	6.9
Average	26.8	33.0	50.3	48.1	15.4	8.9	7.8	9.5

Location Eleven

Sample No.	Montmorillonite D.	Montmorillonite L.	Illite D.	Illite L.	Chlorite D.	Chlorite L.	Kaolinite D.	Kaolinite L.
1.	24.6	35.8	57.5	37.0	8.6	13.6	10.0	13.6
2.	27.5	28.6	55.0	55.0	13.7	11.5	9.3	4.9
3.	22.6	23.6	51.0	51.0	17.5	7.7	8.7	17.4
4.	24.0	32.6	53.0	43.0	16.5	15.5	6.4	9.0
5.	(silt)	(35.0)		(45.5)		(16.3)		(7.3)
6.	17.0	26.2	60.0	52.5	15.0	12.6	6.5	8.4
Average	23.1	29.3	55.3	47.7	14.2	12.1	8.0	10.6

Location Fifteen

Sample No.	Montmorillonite D.*	Montmorillonite L.*	Illite D.	Illite L.	Chlorite D.	Chlorite L.	Kaolinite D.	Kaolinite L.
A.	32.0	31.0	42.0	48.0	20.0	14.0	5.5	5.3
B.	27.0	28.0	52.0	51.0	12.0	14.0	8.2	6.5
C.	20.0	26.0	59.0	52.0	19.4	7.3	1.2	14.6
D.	30.0	29.0	48.0	59.0	11.0	9.9	10.0	5.8
E.	29.0	39.4	54.0	45.0	8.7	10.0	8.6	5.8
Average	25.5	30.6	51.1	51.1	14.3	11.0	6.7	6.9

(D. means "dark layer   L. means "light layer")

According to the density values of the clay minerals, illite and chlorite should settle out first concentrating in the light colored summer layers, with kaolinite and montmorillonite settling later during the quiet non-influx period concentrating in the dark colored winter components. The data in Table 1 shows that actually the reverse is true, indicating that the densities were not critical in the differential sedimentation of the Lake Missoula clay minerals.

The third explanation that differential sedimentation rates caused by the flocculating properties of the clay minerals is believed to be the factor which controlled the observed differentiation of the Lake Missoula clay minerals in the Pleistocene lake waters. Whitehouse and Jeffrey (1955, p. 274) report in a study of peptization resistances of clay minerals with various alkaline dispersing agents that the order of increasing stability in suspension is montmorillonite-kaolinite-illite.

Differential sedimentation caused by variabilities in the flocculating properties of the clay minerals appears to be the factor which concentrated illite and chlorite in the dark winter layers and montmorillonite and kaolinite in the light summer layers. Silt-laden waters entered the submerged Missoula Valley during the summer melt period, at which time, the sedimentation rate of kaolinite and montmorillonite exceeded that of illite and chlorite. During the winter when the sedimentation rate was low, illite and chlorite flocculated in excess of montmorillonite and kaolinite.

The effectiveness of differential sedimentation seems to vary with different clay minerals. Figures 12 and 13 are plots of illite against montmorillonite and chlorite against kaolinite in both summer

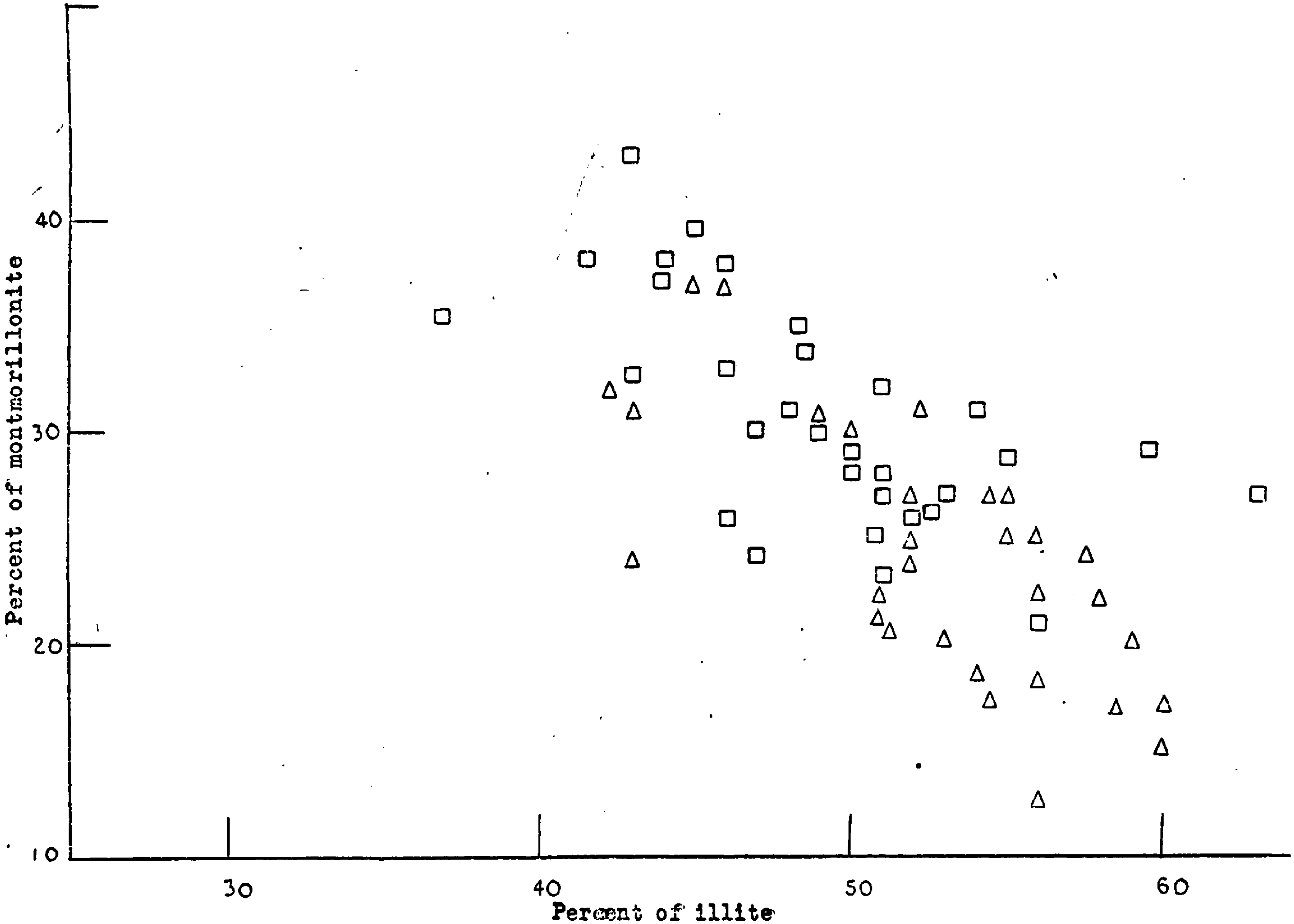


Fig. 12 Plots of illite against montmorillonite △ (Dark layers) □ (Light layers)

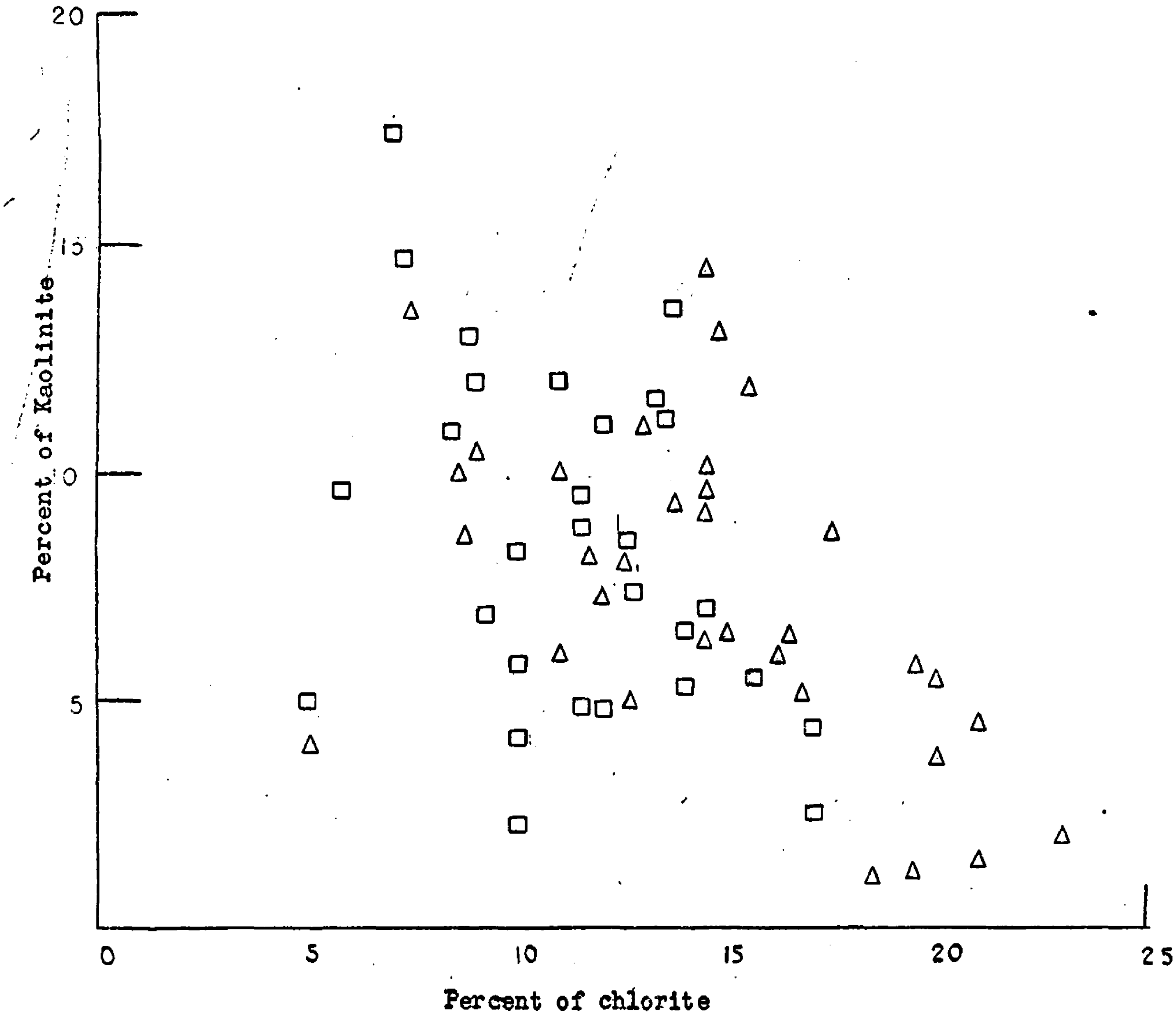


Fig. 13 Plots of chlorite against kaolinite △ (Dark layers) □(Light layers)

and winter layers respectively. Figure 12 shows that illite is concentrated in the winter layers. In Figure 13 there is no apparent difference in the relative amounts of kaolinite and chlorite. This suggests that the flocculating mechanism was more effective in separating montmorillonite and illite from suspension than kaolinite and chlorite.

Correlation of Varved Clays One of the objectives of this study was to determine the geographic distribution of the clay minerals at a specific time. To do this, the strata would have to be correlated. The method of correlation attempted was that of Antevs (1922), based on variations in varve thicknesses.

The strata at the various locations could not be correlated. Other types of information obtained were the average thicknesses in each section. Two obviously correlative sections 75 yards apart were measured specifically for the purpose of testing the feasibility of the correlating technique. Plate 5 shows that these two sections could be correlated by the varve thickness technique.

Stratigraphic Changes in the Clay Mineral Suite Locations One, Two, and Eleven are believed to represent sections of increasing relative age. This is based on evidence presented on pages 9, 12, 13. Examination of the clay minerals from the three sections shows no detectable changes in the clay mineral suite (Table 1). The consistency of the clay mineral suite indicates little change of environmental conditions at the source or at the depositional areas.

Results of Potassium Fixation Some montmorillonites subjected to potassium hydroxide treatments will contract to 10 Å. This contraction indicates a net negative tetrahedral charge inherited from a mica type source material. Little or no collapse results from a relatively low net negative tetrahedral charge present in montmorillonites originating from a non-micaceous source (Weaver, 1958, pp. 839-859).

The treated samples did not contract and upon glycolation expanded to 17 Å. This indicates a non-micaceous source. The montmorillonites were probably derived from the Tertiary sediments in the Blackfoot Valley (p. 5).

Horizontal Distribution of Clay Minerals in Missoula Valley The average percentages of the clay minerals from the dark and light layers at each location were plotted against distance from Location Fifteen which is believed to be the initial site of deposition of material in Lake Missoula derived from the Blackfoot Glacier. A systematic distribution of the clay minerals with the exception of erratic points at Location Eight, is evident in Figures 14, 15, and 16. It is realized that any conclusions reached from this distribution will be based on limited data, nevertheless the trends appear to be significant enough to warrant discussion.

Horizontal Distribution of Illite and Montmorillonite Figure 14 shows the trends in abundance of illite in the dark and light layers with increasing distance from the site of initial deposition. The abundance of illite in the dark layers increases with distance; the abundance of illite in the light layers decreases with distance. Plots of montmorillonite show a decrease in abundance with distance in both light and dark layers (Fig. 15).

Comparison of illite and montmorillonite (dark layers) shows an

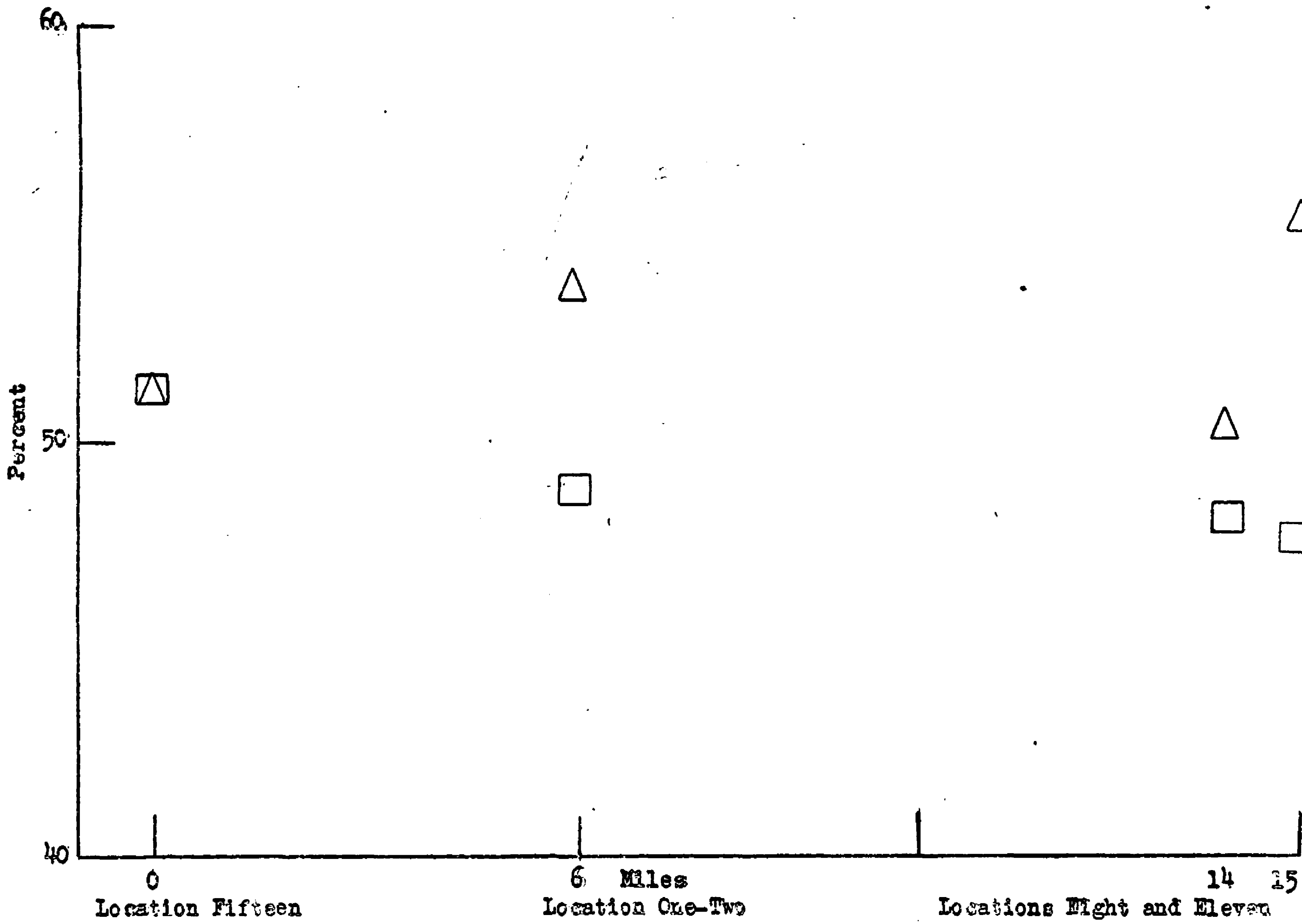


Fig. 14 Horizontal distribution of illite. △ (Dark Layers) □ (Light Layers)

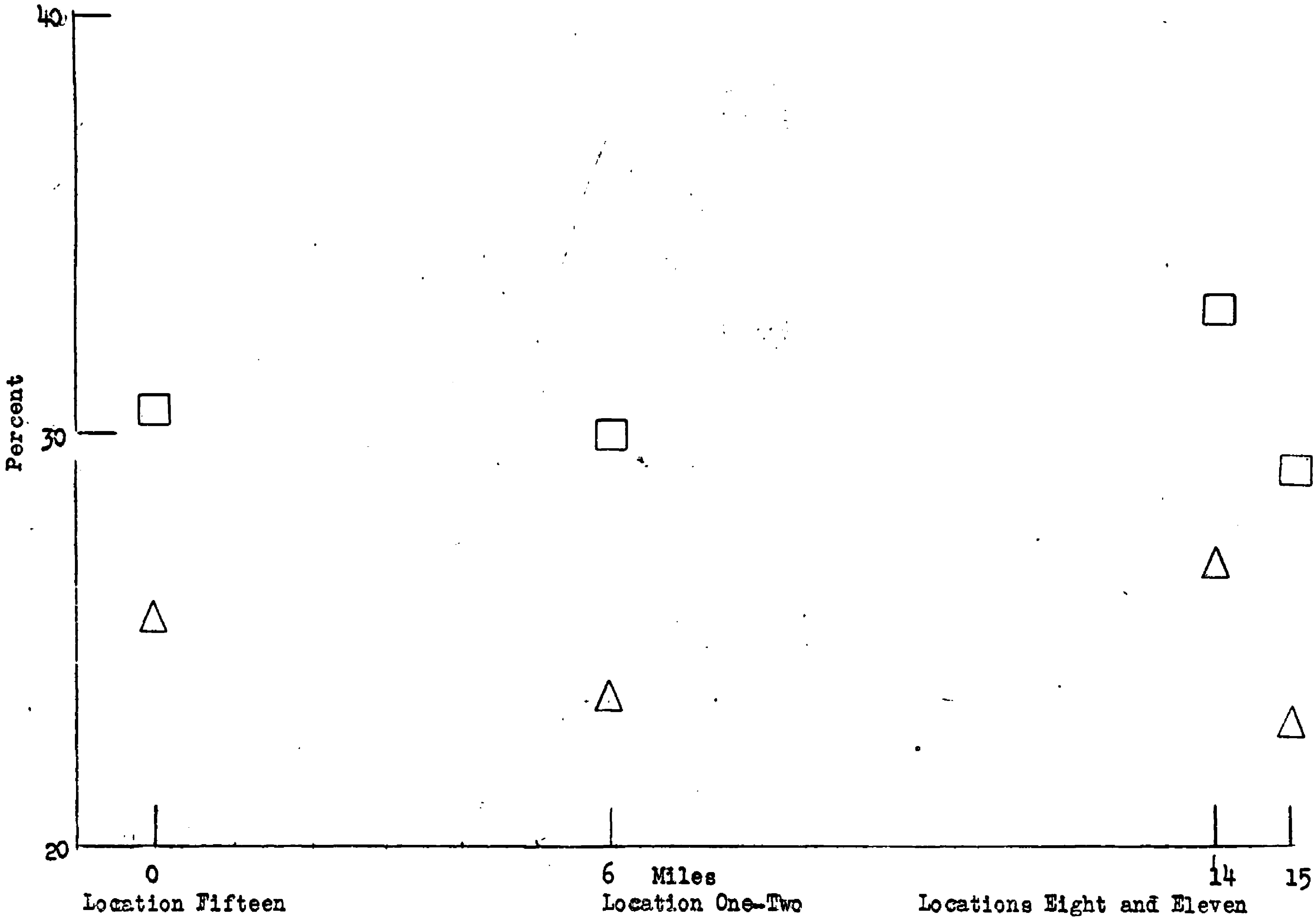


Fig. 15 Horizontal distribution of montmorillonite △ (Dark layers) □ (Light layers)

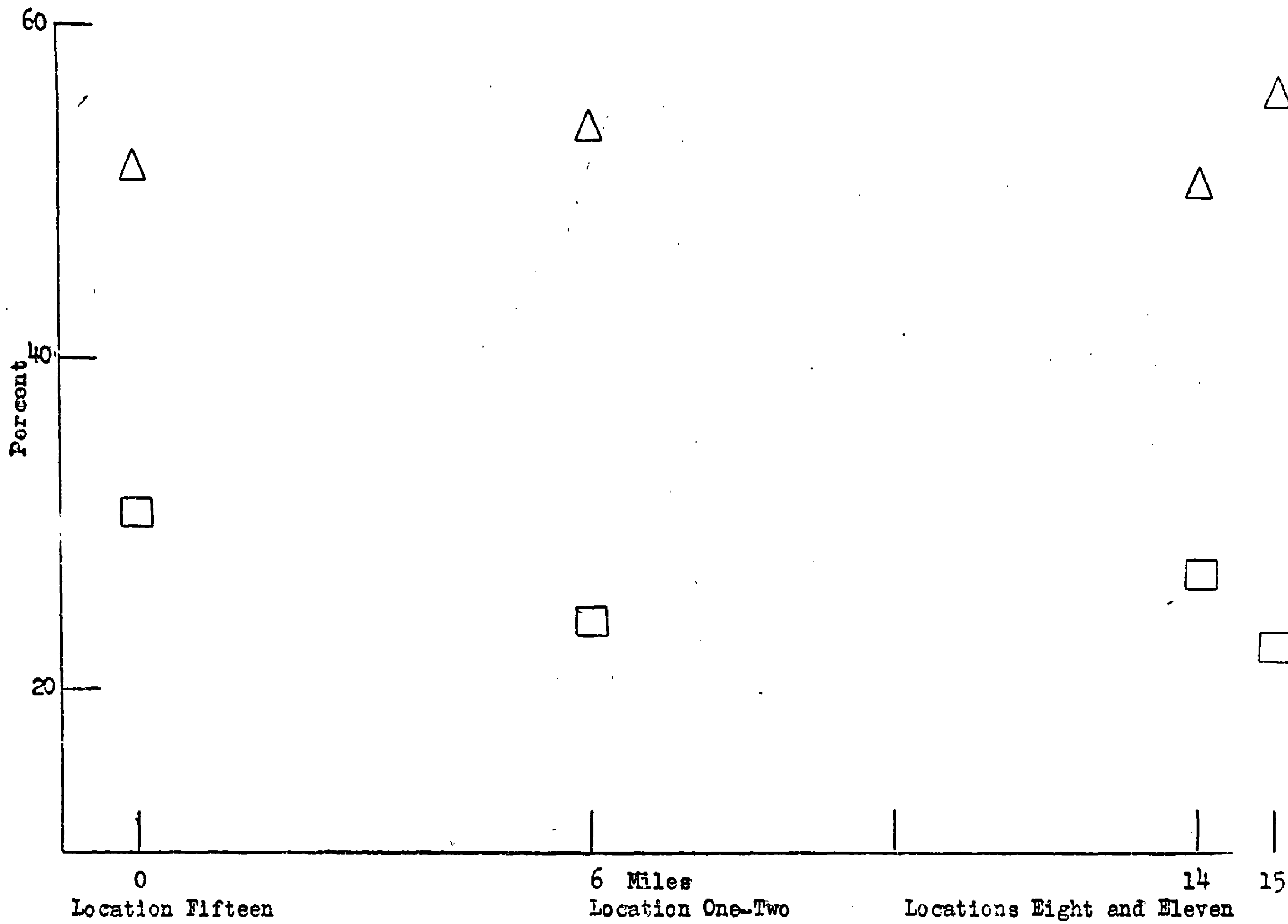


Fig. 16 Horizontal distribution of illite and montmorillonite.
△ (Dark layer illite) □ (dark layer montmorillonite)

apparent increase in illite and decrease in montmorillonite (Fig. 16). The apparent increase in illite and decrease in montmorillonite is believed to be controlled by the nature of the flocculates. The stability of illite in suspension prevents early flocculation. Therefore illite increases with distance from the source. Montmorillonite flocculates more quickly and therefore decreases with distance. Rolfe (1957, pp. 378-380) in a study of Lake Mead sediments reported a similar relationship. In the upstream end of the lake, montmorillonite is dominant, while in the downstream end of the lake, illite is dominant. He believed the change in composition was due to "sedimentation in a natural flocculating environment." Many investigators have noted similar trends in Recent sediment studies and attributed the changes to diagenesis (Grim and Johns, 1954; Brown and Ingram, 1954).

The equal amounts of illite in the dark and light layers add further evidence that a flocculating mechanism was the predominant control in the observed clay changes (Fig. 14). Location Fifteen appears to have been an area of initial deposition in Glacial Lake Missoula. The sedimentation rate was high, as shown by the thick varves. Consequently, any differentiation due to flocculation variations in the clay minerals would tend to be obscured, resulting in the same abundance of the clay minerals in the dark and light layers. The equal abundance was observed. Changes in the amounts of illite were not observed until at Location One (Fig. 14). At this point the sedimentation was probably controlled less by influx rate and more by the nature of the flocculates.

<u>Horizontal Distribution of Chlorite and Kaolinite</u> Plots of chlorite

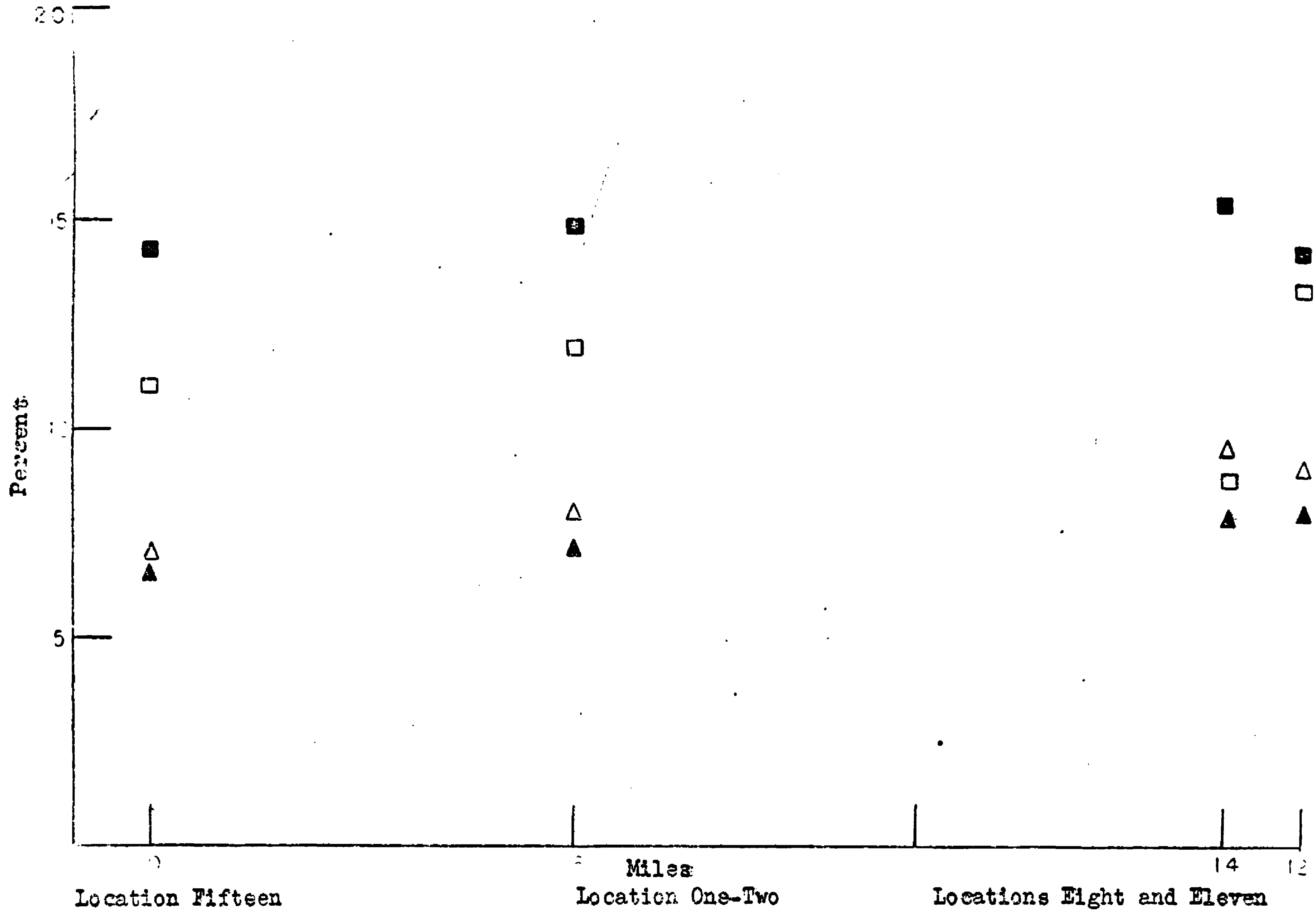


Fig. 17 Horizontal distribution of chlorite and kaolinite ▫ (Light layers chlorite)
▲ (Dark layers kaolinite) △ (Light layers kaolinite) ▪ (Dark layers chlorite)

indicate no apparent change with distance; kaolinite shows an increase with distance (Fig. 17). From the conclusions reached on page it would seem that chlorite-illite and montmorillonite-kaolinite should exhibit parallel trends. As discussed on page 23 the abundances of montmorillonite and illite are detectably different in the summer and winter layers. The relative amounts of chlorite and kaolinite are not.

<u>Calcium Carbonate Content</u> Dark material from Location Fifteen and light material from Location Eleven were analyzed for calcium carbonate. The analyses showed approximately 8.8% in the light layers and 4.0% in the dark layers. These results are interesting in the light of studies made by Burwash (1938, from Eden, 1955, p. 672) who believed that high carbonic acid concentration in the lake waters during the winter season would hold calcium carbonate in solution; during the warmer summer season the carbon dioxide would be driven off, precipitating calcium carbonate. Legget and Bartly (1953) found calcium carbonate only in the light layers of the Steep Rock Lake clays. Wallace (1927 from Eden, 1955, p. 673) reported more calcium carbonate in the light layers. The presence of calcium carbonate in the dark winter layers indicate that either the Lake Missoula waters were saturated with calcium carbonate or that the carbonic acid content was low, either case leading to precipitation of calcareous material during the winter season.

<u>Areas Adjoining Missoula Valley</u> No significant changes in the clay mineral types are apparent in the nearby areas (Table 2). A high abundance of illite (65.0%) is present at Location Thirteen (Fig. 2). This area is the closest sampling point to the Blackfoot glacial source.

Table II
PERCENTAGES OF CLAY MINERALS IN ADJOINING AREAS

Location Twelve (One-half mile NE of Bonner)

Sample No.	Montmorillonite	Illite	Chlorite	Kaolinite
1.	34.4	36.2	10.5	11.5

Location Thirteen

Sample No.	Montmorillonite D.	Montmorillonite L.	Illite D.	Illite L.	Chlorite D.	Chlorite L.	Kaolinite D.	Kaolinite L.
1.	12.4	38.0	65.0	45.7	17.0	8.7	5.2	7.8

Location Twenty-One (35 miles west of Missoula)

Sample No.	Montmorillonite	Illite	Chlorite	Kaolinite
1	41.5	41.0	8.6	8.6

Location Twenty-Two

Sample No.	Montmorillonite D.	Montmorillonite L.	Illite D.	Illite L.	Chlorite D.	Chlorite L.	Kaolinite D.	Kaolinite L.
1	30.4	37.4	44.0	52.5	11.6	8.8	9.7	5.2

Location Thirty

Sample No.	Montmorillonite D.	Montmorillonite L.	Illite D.	Illite L.	Chlorite D.	Chlorite L.	Kaolinite D.	Kaolinite L.
1	31.8	*	51.0		11.4		6.1	
2	33.0	28.4	51.0	48.0	14.8	9.7	1.0	11.7
3	32.6	40.0	52.0	48.0	11.0	11.0	3.6	1.0
4	25.6	35.0	52.0	48.5	16.7	9.4	5.7	7.6
5	37.0	32.0	50.0	47.5	14.5	7.1	4.5	11.9
Average	32.0	33.5	51.3	48.0	13.6	9.3	4.1	8.0

Location J-One (Jocko Valley)

Sample No.	Montmorillonite	Illite	Chlorite	Kaolinite
1	18.5	56.0	20.0	5.0

* Sample was not taken due to weathering.

The varved sediments exposed in Location Thirty resemble closely the sediments in Location Two in that both contain four distinct equally spaced sand layers. No correlation based on this similarity is possible as the sand layers in Location Two pinch out approximately two miles west.

It is not known conclusively whether the sediments of Location Thirty were derived from the easterly glacial sources or from possible sources to the southwest (Fig. 2). This location is farthest west from the easterly glacial sources and, significantly the grain size analyses show lesser amounts of coarse material as compared to the locations in Missoula Valley.

If the source of the sediments was from the easterly glaciers, then the apparent horizontal increase of illite and decrease of montmorillonite with distance is not evident here (Table 2). However, it appears probable from study of a glacial map of the area (Fig. 2) that the sediments were derived from southwest.

Significance of Differential Sedimentation in Present Clay Problems

Opinion as to the importance of diagenetic effects on clay minerals in marine environments is divided. Grim (1953, p. 352) states that a most important diagenetic effort in this environment is the reconstitution of degraded mica and chlorite by absorption of K and Mg. A less important change is the slow alteration of montmorillonite and Kaolinite structures to illite and chlorite by diagenesis.

Weaver (1958, p. 254) argues that the majority of clays found in sedimentary rocks and in depositional basins reflect their source, and the only process affecting clay minerals in marine environments is cation adsorption by degraded micas. It should be mentioned here that cation adsorption is the same process as Grim's reconstitution of degraded micas, which was mentioned above. Weaver states further that the effect of diagenesis has been overemphasized.

A review of the literature shows that diagenesis is strongly advanced to explain clay mineral changes in marine environments. Dietz (1941, taken from Murray and Sayyab, 1954, p. 433) reported that illite is the prominent clay mineral in Recent sediments being abundant far from shore, whereas montmorillonite and kaolinite are more abundant near shore. Grim, Dietz, and Bradley (1949) found in a study of Recent sediments off the coast of California that illite, chlorite, kaolinite, and montmorillonite are present, with illite being the most abundant and kaolinite the least abundant. They believe that kaolinite is altered to chlorite and montmorillonite by diagenetic changes.

Brown and Ingram (1954) identified kaolinite, illite, montmorillonite, chlorite, and mixed layer aggregates in the Neuse River, North Carolina. They found a downstream decrease of kaolinite and montmorillonite concomitant with an increase of chlorite and mixed layered chlorite-illite. They concluded these changes were due to alterations of kaolinite and montmorillonite into chlorite and mixed layered chlorites-illites by diagenesis.

Grim and Johns (1954) found montmorillonite, illite, chlorite, and some kaolinite in the northern Gulf of Mexico. They reported an increase in illite and chlorite and a decrease of montmorillonite in passing into the Gulf from the Guadalupe River. It was concluded these changes were due to transformation of montmorillonite to chlorite and illite. Significantly, differential sedimentation was held to be a factor "which could not be ruled out."

Murray and Sayyab (1955) reported illite, chlorite, and mixed layered illites-chlorites and illites-montmorillonites. They found structural changes in the clay minerals with distance from shore and depth, rather than changes in clay mineral types. The structural changes were attributed to diagenesis.

Milne and Early (1958) report in a study of clay minerals from the Mississippi Delta area that there were no significant changes in the clay mineralogy except in the areas of slow sedimentation where illite develops from montmorillonite by diagenesis. It was concluded that the clay mineral suite is dependent upon the character of the source area.

Weaver (1959) reviewed the literature of Recent marine sediment investigations finding that most variations in the clay mineral distribution in the ocean have been explained by alteration and modification of pre-existing clay minerals. He concludes that clay minerals are primarily detrital in origin, reflecting the source areas.

Many investigators have postulated diagenetic changes in Recent sediments caused by the marine environment when a river upon entering the sea shows an increase in abundance of one or more clay minerals (usually montmorillonite and kaolinite). Weaver presents convincing evidence that these changes could be explained by other hypotheses. One of these hypotheses is preferential flocculation.

As argued by Weaver, diagenesis has been overemphasized as the primary cause for variations in clay minerals in Recent sediments. The study of clay minerals in Glacial Lake Missoula sediments shows that the variations in clay minerals can be caused by mechanisms other than diagenesis. For the Lake Missoula sediments differential sedimentation or preferential flocculation appears to be the most logical explanation. The effects of this mechanism are the segregation of the clay mineral suite, concentrating illite and chlorite in the dark winter layers, montmorillonite and kaolinite in the light summer layers, and increase in illite and decrease in montmorillonite with distance from source. These variations are found in a glacial environment where chemical activity was probably very low, and certainly no appreciable amount of potassium was available to convert montmorillonite to illite.

SUMMARY AND CONCLUSIONS

1. The varved sediments of Missoula Valley consist of simple, composite, and drainage varves.

2. Simple and composite varves suggest that the depositional conditions varied in the Missoula Basin. Normal seasonal changes produced simple varves, while marked variations in weather, intermittent mud-flows, and stratified lake waters produced the rare composite varves.

3. The seasonal segregation of the Missoula clay mineral suite indicates that illite and chlorite are more stable in suspension than montmorillonite and kaolinite.

4. The nature of the colloidal system was such that illite and montmorillonite were more effectively differentiated than chlorite and kaolinite.

5. Horizontal increases in illite and decreases in montmorillonite with distance from source are also caused by differential sedimentation.

6. The most significant result of this study is that variations in clay mineral suites can be produced by mechanisms other than diagenesis.

APPENDIX

The sediments studied are locally exposed in railroad and highway cuts. The usual procedure for collecting field data was to cut a series of steps up the railroad and highway cuts, shaping smooth, vertical faces on each step. The actual thicknesses of the varves were plotted directly on a roll of adding machine paper and later transferred to graph paper. The thickness of the lowest varve was plotted on the first vertical line, the thickness of the second on the next vertical line, etc. All the points were connected and compared with graphs from other locations (Antevs, 1922, p. 4).

Blocks of material were chiseled out approximately every two feet in each vertical section and stored in plastic bags. The banded layers of each sample were mechanically separated. Representative amounts of dark and light material were dispersed separately in 1000 ml. cylinders using sodium metaphosphate as a dispersing agent. After eight hours and ten minutes a pipette was inserted to a depth of ten cm and twenty cc of material (2) was withdrawn and stored in plastic bags for later x-ray analysis.

Surveying Elevation determinations of Locations One, Two, and Eleven, and Eight were made with a transit. Reference points along Highway 10 were obtained from the Montana State Highway Department; U. S. Coast and Geodetic bench marks were used along the railroad cuts.

Grain Size Analyses Representative amounts of dark and light material from each location were oven dried for forty-eight hours, and analyzed for sand, clay, and silt content. Grain size analyses were made with the Buoyoucos soil hydrometer (Krumbein and Pettijohn, 1938, p. 172).

Potassium Hydroxide Treatments A number of samples were subjected to potassium hydroxide in order to identify the source mineral of the montmorillonite clays (Weaver, 1958, p. 839). Each sample was soaked in 2 N solutions for forty-eight hours, washed with distilled water, and x-rayed. Patterns were obtained on both untreated and glycolated samples.

Calcium Carbonate Analysis Twenty grams of oven dried light and dark material were treated with concentrated hydrochloric acid until no further reaction was noted. The samples were washed, oven dried, and weighed. The loss in weight was ascribed to calcium carbonate.

Clay Size Material Suspensions of clay size material were centrifuged on unglazed porcelain plates in order to obtain maximum orientation parallel the basal plane (Kinter and Diamond, 1956). X-ray patterns were obtained with a Norelco diffractometer, utilizing copper K alpha radiation. The scanning rate was one degree per minute; the chart rate one-half inch per minute.

Preliminary x-ray diffraction patterns of air-dried samples revealed (001) peaks at 15 A, 10 A, and 7.1 A which are respectively montmorillonite (containing two water layers), illite, and kaolinite or chlorite. After glycol treatment the 15 A peak shifted to 17 A indicating montmorillonite was present. A lesser peak at 14.5 A, indicative of chlorite, was confirmed by heat treating at about 600 C^{o}. Since (001) kaolinite and (002) chlorite both occur at about 7 A, further treatment was necessary to confirm the presence of kaolinite (Fig. 18).

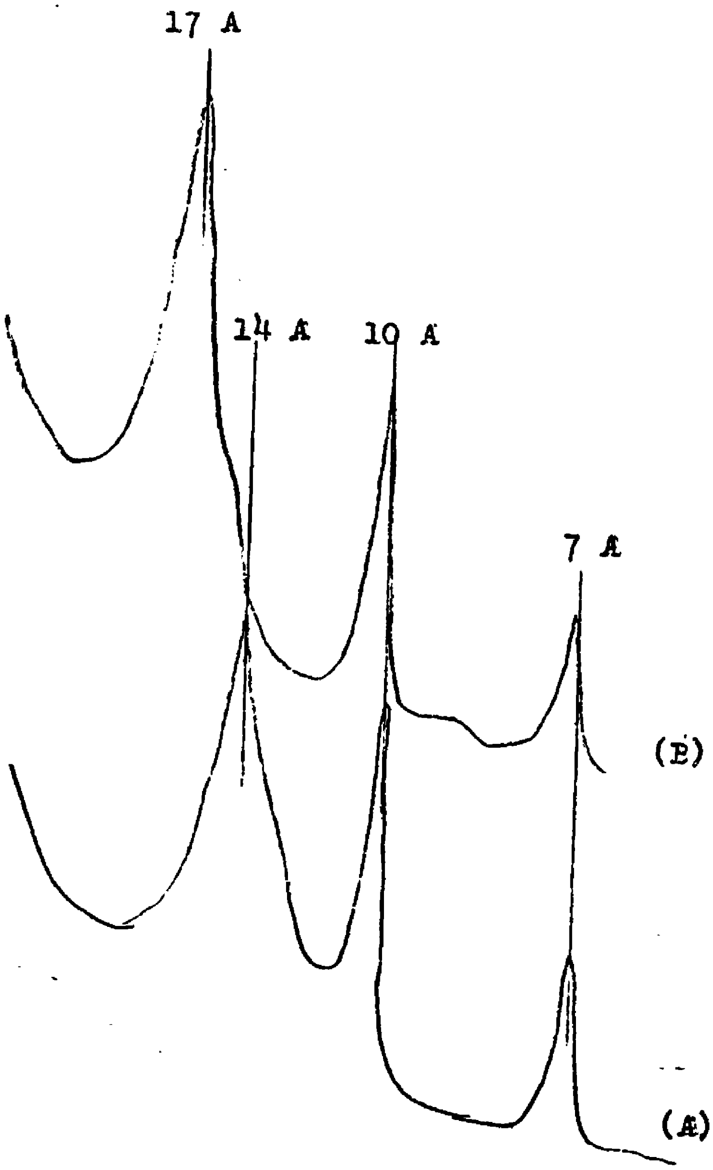


Fig. 18 Typical diffractometer patterns of Missoula clays
(A) Air dried sample (B) (Glycolated sample)

Quanitative Analysis Procedure The procedure for the quantitative analysis of clay minerals was taken from Johns, Grim, and Bradley, (1954, p. 242). The method is based on the premise that the 3.5 A reflection of chlorite and kaolinite can be compared to the 3.3 A reflection of illite since the scattering distribution at these angles are approximately equal. The 10 A reflection of illite which is one-fourth intense as the 15 A reflection of montmorillonite, is increased by a factor of four. The corrected intensity of the 10 A illite reflection is then compared to the 17 A intensity of montmorillonite.

Johns, et al. found that if a sample is heated to 450° C for approximately forty minutes the chlorite contribution to the 3.5 reflection would be eliminated, while kaolinite would be unaffected at this temperature. However, the thermal stability of chlorite varies with composition and degree of crystalline perfection of the structure. The chlorite of the Lake Missoula sediments did not respond to heat treatments, and it was necessary to eliminate instead, the kaolinite by boiling in 1 N sodium hydroxide for an hour.

The procedure was to first x-ray the air-dried samples, measuring the area under the 3.5 A and 3.3 A (003 of illite). The three components contributing to the 3.5 A peak are chlorite (004), kaolinite (002), and montmorillonite (004). Next the sample was glycoled and x-rayed, and the c.5 A, 17 A and 10 A peaks were measured. With this treatment the 3.5 A reflection decreased due to shifting of the (004) of montmorillonite. Finally, after the sodium hydroxide and heat treatments, only the chlorite (004) contributed to the 3.5 A peak. The difference between this measured value and the value of the glycoled sample is the kaolinite equivalent (Fig.19).

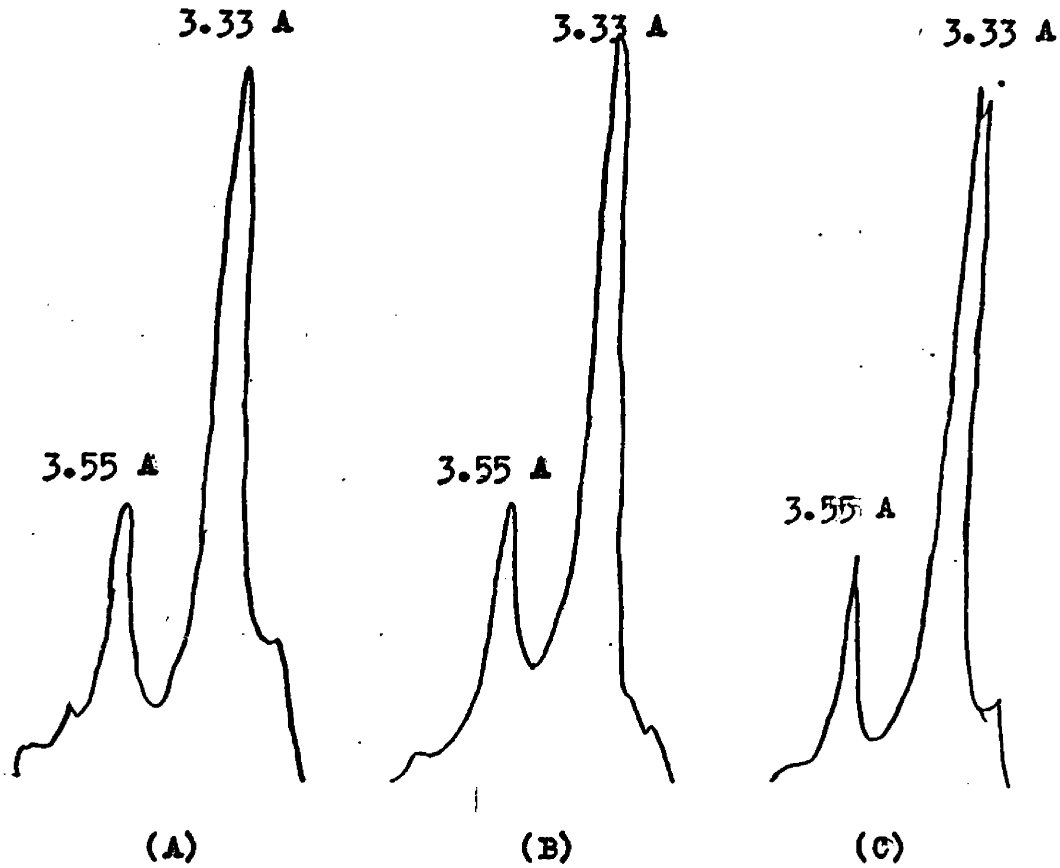


Fig. 19 Changes in the 3.55 Å peak after various treatments.
(A) Air dried (B) Glycolated (C) KOH and heat treatments

For example, in sample 30-D (Table 3 and Fig.19), the intensity of the 3.5 A reflection in the air-dried sample is 30, and after glycol treatment it reduces to 28, the change being attributed to montmorillonite. Following sodium hydroxide treatment and heat treatment, the intensity is 18 which constitutes the chlorite contribution. The difference between 30 and 18 would then be the kaolinite value. The relative intensities of the chlorite, kaolinite, and montmorillonite are converted to parts per one part illite, and finally the percentages of the minerals are calculated.

Intensities were measured by tracing background corrected peaks of the clay minerals on special drafting paper. The drawn peaks were cut out and weighed. The entire area could be accurately measured in this way.

Table 3 Analytical Data for Sample 30

A. Relative Intensity Data

17 A	10 A	3.5 A	3.3 A	Comments
160	64		83	
	256			Illite corrected
		30		
		28		Corrected for montmorillonite
		10		Kaolinite corrected for chlorite
		18		chlorite

B. Clay Mineral Composition

Montmorillonite	Illite	Chlorite	Kaolinite	Comments
.62	1	.21	.12	Parts per one part illite
31.8	51.0	11.4	6.1	Approximate percentage of each constituent.

Analyses of Recent Sediments from the Clark Fork

A sample was collected from the Clark Fork River and the clay mineral content was determined with a diffractometer (Table 4). The clay mineral suite of the Recent sediments as compared to the clay mineral suite of the Pleistocene Missoula lacustrine sediments did not differ significantly.

Table 4

Montmorillonite	Illite	Chlorite	Kaolinite
41.5 %	51.4 %	4.6 %	2.6 %

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UNIVERSITY OF MONTANA

May 17, 1983

Erling Oelz, Acting Dean, Library

Susan Carkeek, FO/Personnel Services

Classification Review

As a result of the classification review conducted by the State Personnel Division, the following title changes will be implemented:

	Old Title	New Title
Linda Harris (IMS)	Library Assistant I	Library Technician I
Phil Marsh	Library Assistant I	Library Technician I
Harriet Ranney	Library Assistant II	Library Technician II
Sally Bullers	Library Assistant II	Library Technician II
Constance Piquette	Library Assistant II	Library Technician II
Elizabeth Weber	Library Assistant II	Library Technician II
Richard Ives	Library Assistant II	Library Technician II
~~Marie~~ Habener	Library Assistant II	Library Technician II
Donna Tornabene	Library Assistant II	Library Technician II
Kirk Flynn (IMS)	Library Assistant III	Library Technician III
Carol Leese	Library Assistant III	Library Technician III

No grade changes were recommended.

If you have any questions or I can be of any further assistance, please call.

SC/ss

THIS MEMORANDUM WILL SERVE TO INFORM YOU OF THE RESULTS OF THE CLASSIFICATION REVIEW CONDUCTED LAST YEAR. A COPY OF THE REVISED "CLASS SPECIFICATIONS" IS AVAILABLE IN THE RESERVE BOOK ROOM FOR YOUR EXAMINATION.

E. OELZ

CC: Hatcher, P. Johnson, Elison, Chandler